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(54) **SYSTEMS AND METHODS FOR DETERMINING OSCILLATIONS OF A TIRE**

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G01M 7/02 (2006.01)
B60C 99/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G01M 7/02*** (2013.01); ***B60C 99/006*** (2013.04); ***G01M 17/02*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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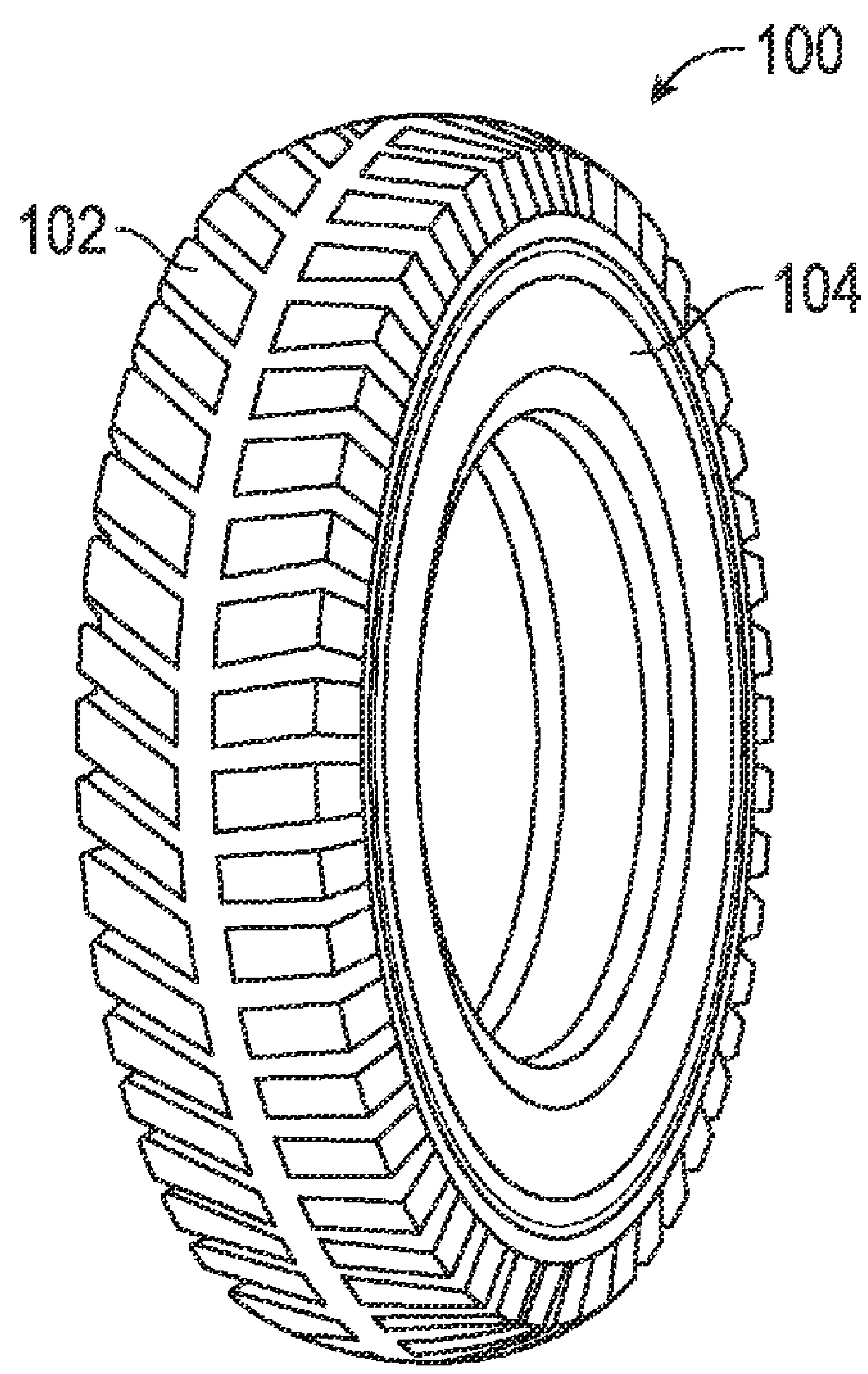
(57) **ABSTRACT**

Methods and systems are provided for determining frequencies associated with tire crown bending. The system includes a vibration generating device configured to excite vibrations through a tire. The system further includes a vibration sensing arrangement configured to sense vibrations at a plurality of sensing points on the tire. A computer is in communication with the vibration sensing arrangement and configured to determine a first frequency associated with bending of the crown of the tire based at least partially on phase differences between the sensed vibrations at the plurality of points on the tire.

18 Claims, 4 Drawing Sheets



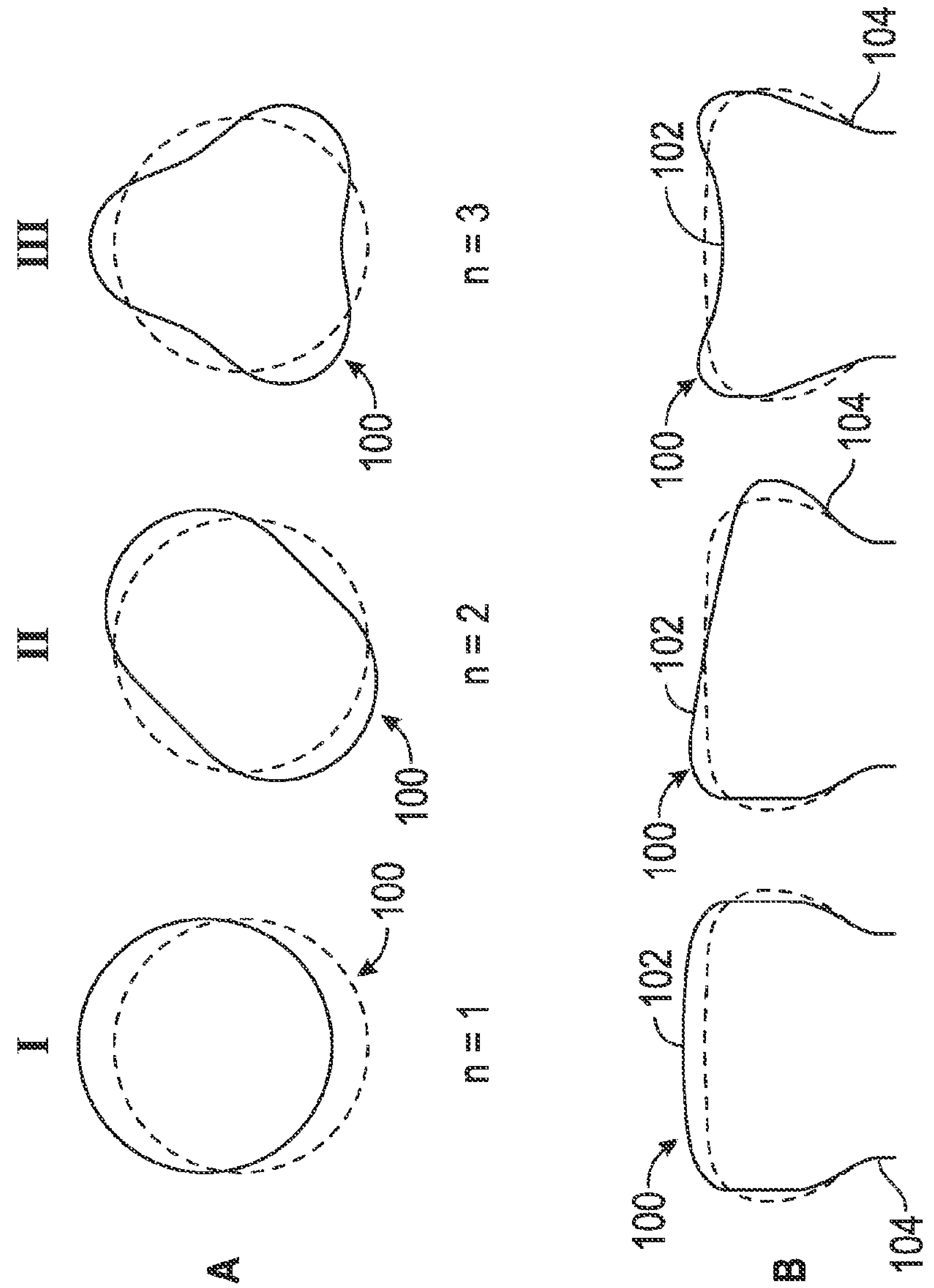


FIG. 2

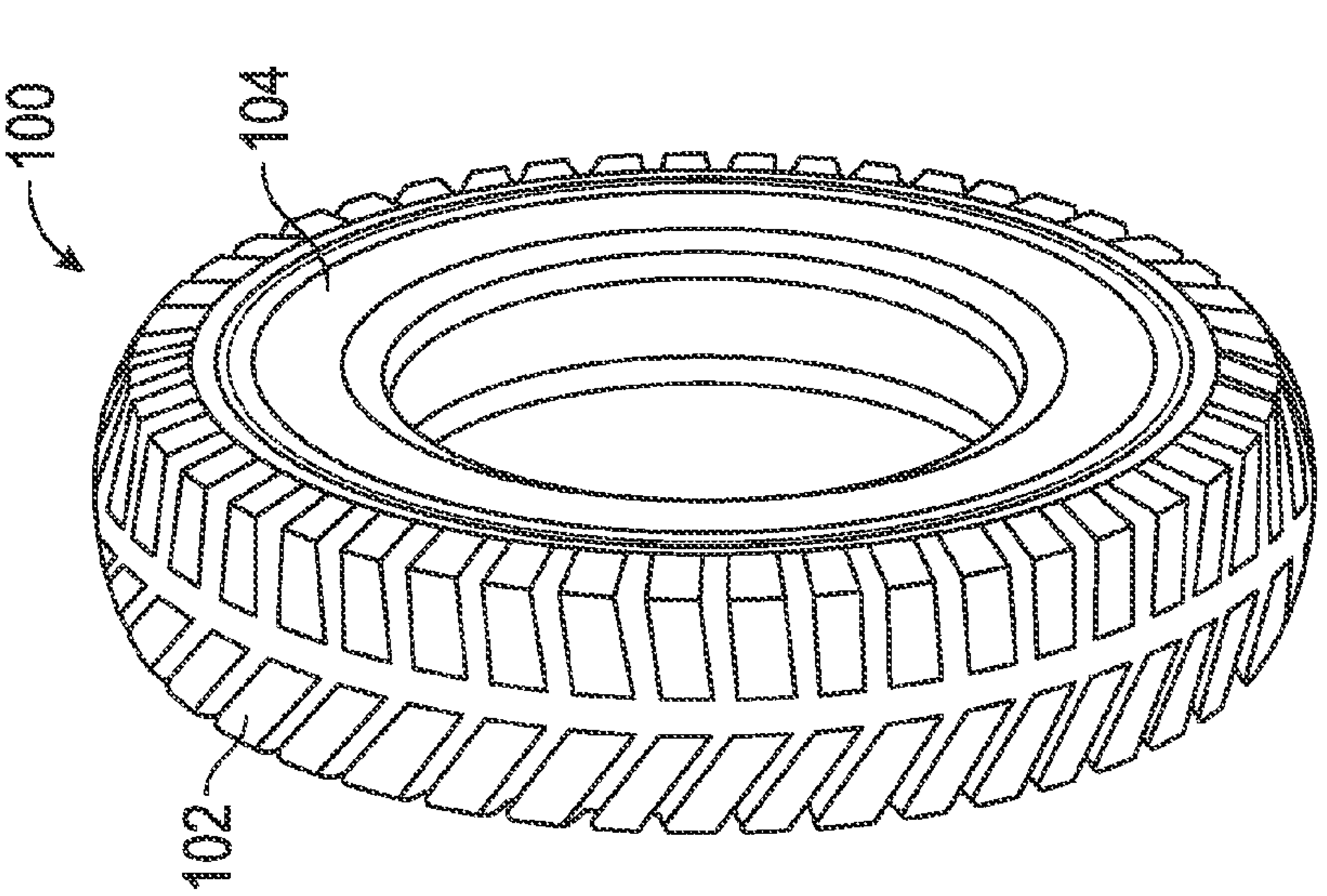


FIG. 1

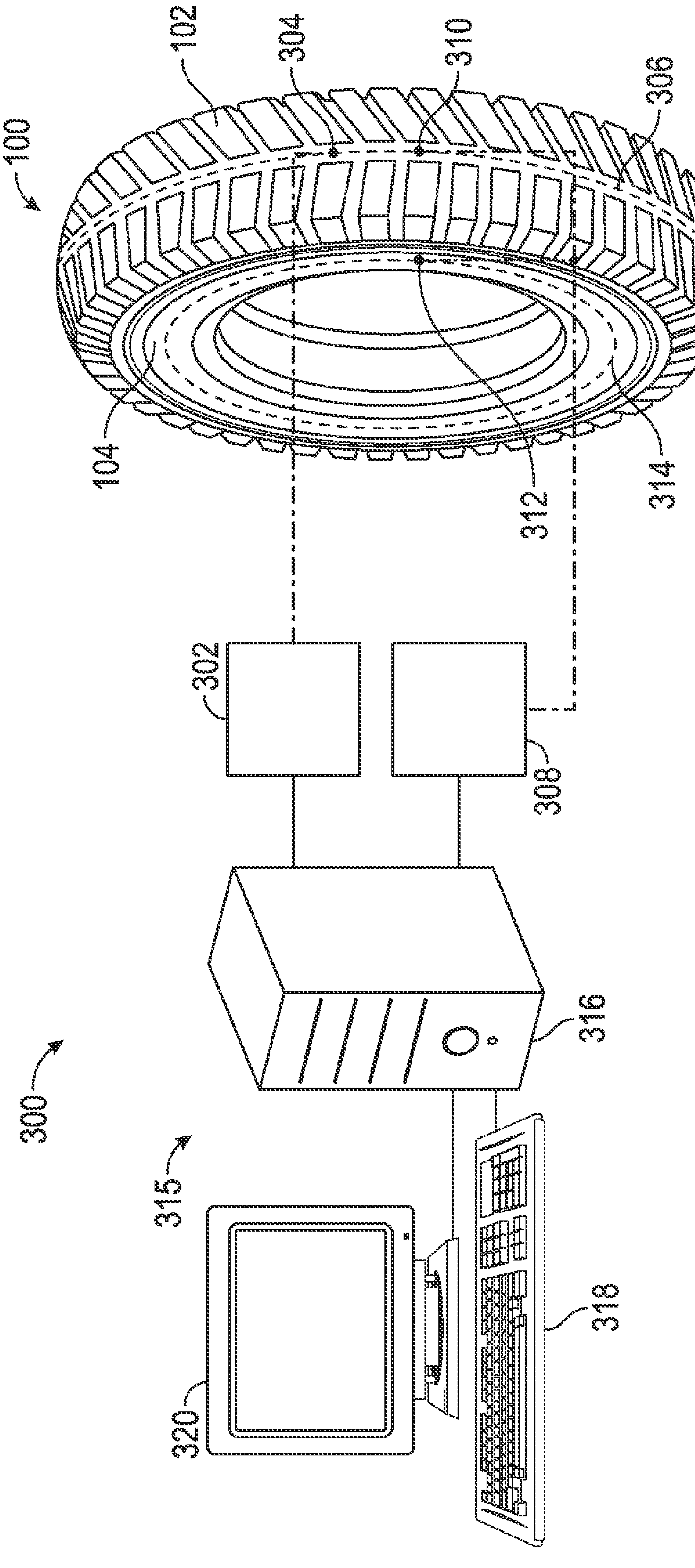


FIG. 3

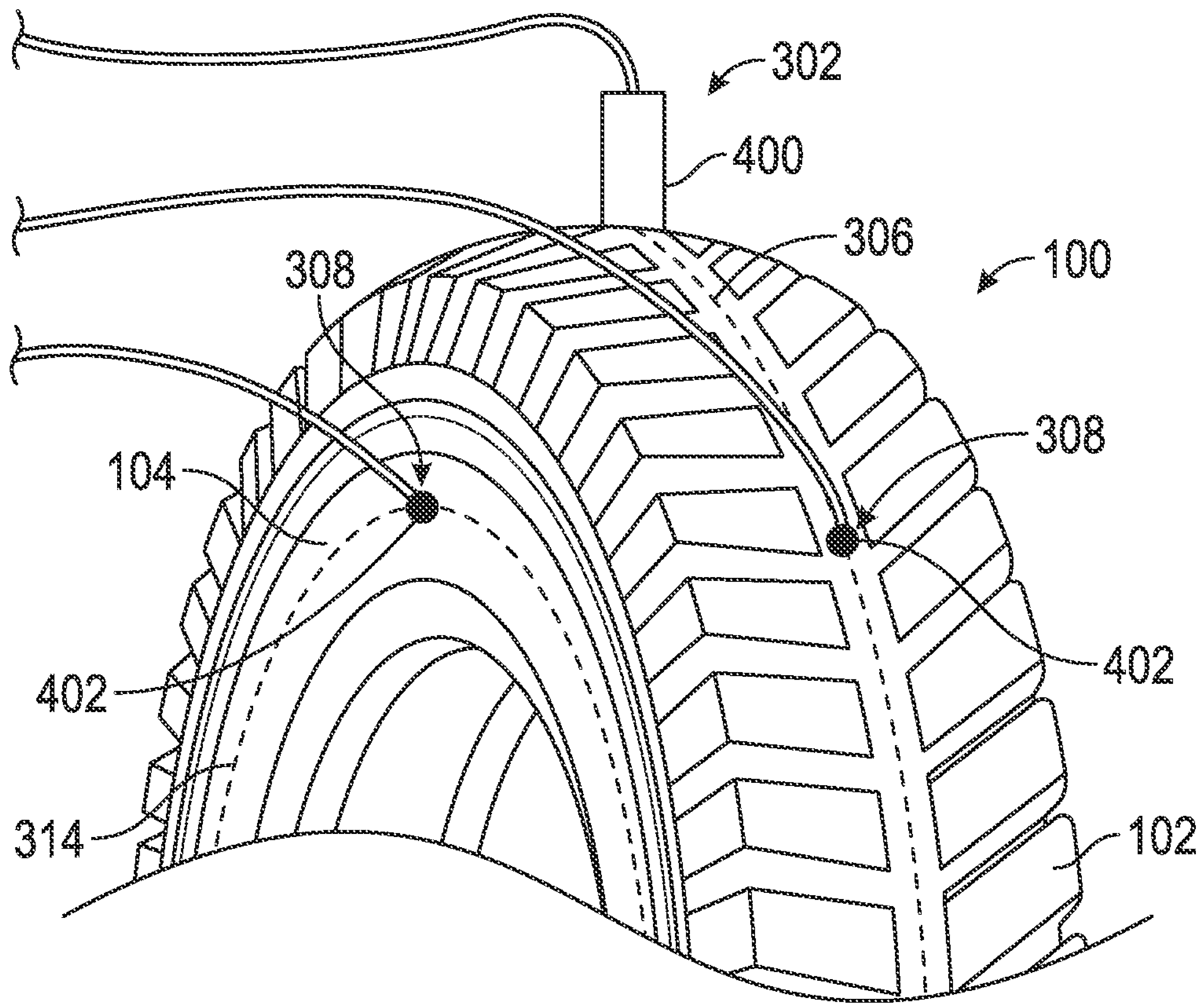


FIG. 4

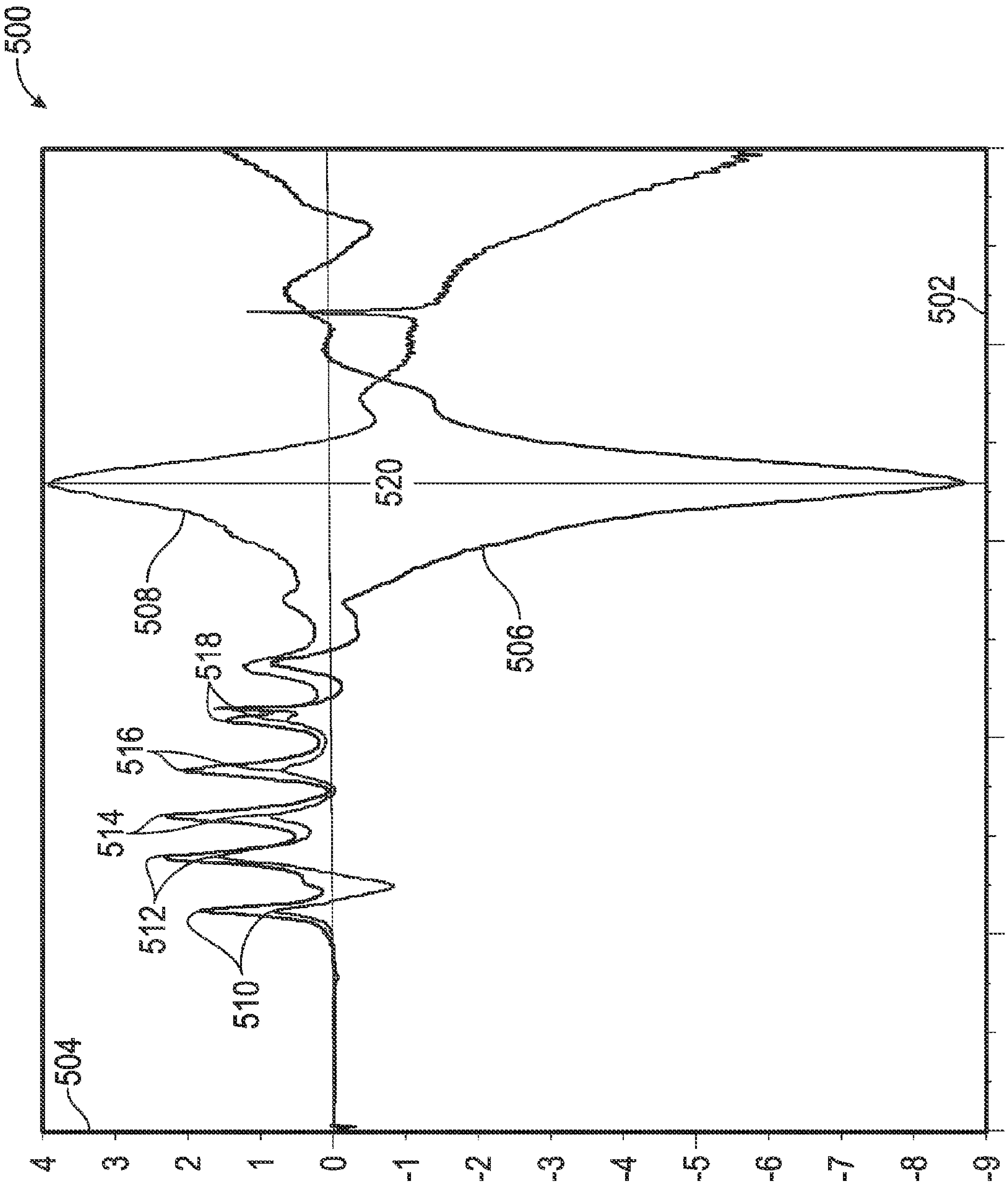

500
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FIG. 5

SYSTEMS AND METHODS FOR DETERMINING OSCILLATIONS OF A TIRE

TECHNICAL FIELD

The technical field generally relates to determining vibrations of a tire, and more particularly relates to determining oscillations of a crown of a tire for a vehicle.

BACKGROUND

Interaction between tires and a road can cause undesired noise that is bothersome to operators and/or other occupants of a vehicle, such as an automobile. In one instance, vibrations of the tires occur, particularly when traversing coarse roads. Coarse roads typically include irregular and/or uneven surfaces. Such surfaces may be associated with, for example, concrete cracks, spalled surfaces, and/or damaged textured surfaces. Operation of a vehicle on such surfaces may result in unwanted passenger compartment noise.

Accordingly, it is desirable to provide a system and method for determining a condition which results in undesired noise when a vehicle is driven on coarse roads. In addition, it is desirable to provide a system and test to check tires that are susceptible to such undesired noises. Furthermore, other desirable features and characteristics of the present invention will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

SUMMARY

A system is provided for determining frequencies associated with tire crown bending. In one embodiment, the system includes a vibration generating device configured to excite vibrations through a tire. The system further includes a vibration sensing arrangement configured to sense vibrations at a plurality of sensing points on the tire. A computer is in communication with the vibration sensing arrangement and configured to determine a first frequency associated with bending of a crown of the tire based at least partially on phase differences between the sensed vibrations at the plurality of points on the tire.

A method is provided for determining frequencies associated with tire crown bending. In one embodiment, the method includes exciting vibrations through a tire and sensing vibrations at a plurality of points on the tire. The method also includes determining a first frequency associated with bending of a crown of the tire based at least partially on phase differences between the sensed vibrations at the plurality of points on the tire.

DESCRIPTION OF THE DRAWINGS

The exemplary embodiments will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a perspective view of a tire in accordance with an embodiment;

FIG. **2** illustrates modes of oscillation of the tire in accordance with an embodiment;

FIG. **3** is a block diagram of a system for determining frequencies associated with bending of a crown of the tire in accordance with an embodiment;

FIG. **4** is a perspective view of the tire showing an impact hammer and a plurality of accelerometers in accordance with an embodiment; and

FIG. **5** is a graph showing magnitude and phase difference between oscillations of a sidewall and a crown of the tire.

DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the application and uses. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

Referring to FIG. **1**, a tire **100** for a vehicle (not shown) includes a crown **102** and a pair of sidewalls **104**. The crown **102** extends around a circumference (not numbered) of the tire **100** and engages the ground and/or road (not shown) when the tire **100** is mounted on the vehicle. The crown **102** typically includes a tread pattern (not numbered) as is well known to those skilled in the art. The sidewalls **104** extend generally perpendicular from each side of the crown **102** for connection of the tire **100** to a wheel (not shown).

All references herein regarding tire vibratory shapes assume the tire **100** is mounted on a wheel and inflated. The tire **100**, when mounted and inflated, may tend to deform, i.e., bend, in a repetitive manner. That is, the tire **100** may oscillate with disproportionately large amplitude at specific frequencies based on numerous factors, including, but not limited to, the specific design of the tire **100** (e.g., size, materials, tread pattern, etc.), the characteristics of the ground and/or road, and a speed of rotation of the tire **100**. Selected modes of oscillation of the tire **100** are shown in FIG. **2**. The dotted lines represent the tire **100** without oscillation while the solid lines represent the tire **100** oscillations. Row A of FIG. **2** generally illustrates a side view of the tire **100** along its circumference while Row B illustrates a cross-sectional view of the crown **102** and sidewalls **104** of the tire along its width. A-I of FIG. **2** illustrates a vertical bouncing of the tire **100**, A-II illustrates a second bending of the tire **100**, and A-III illustrates a crown **102** bending of the tire **100** for n=3 with six symmetrically located regions of locally maximal radial activity.

Of particular interest are the frequencies associated with crown bending. Research and development into tires has shown that some structural compositions of tires result in certain modes of crown bending in the range of 250-400 Hz, producing undesired noise in a passenger compartment (not shown) of the vehicle. This is particularly evident for vehicles with unibody construction. Thus, it is desired to determine at what frequency a particular tire will produce vibrations associated with significant crown bending oscillations. More particularly, it is desired to determine a first frequency at which the tire produces vibrations associated with crown bending oscillations. Therefore, with continued reference to the figures, a system **300** and method to determine frequencies associated with crown bending, in particular a first frequency associated with crown bending, is described below.

Referring to FIG. **3**, the system **300** includes a vibration generating device **302**. The vibration generating device **302** is configured to excite vibrations (i.e., oscillations) through the tire **100**. That is, the vibration generating device **302** causes the tire **100** to vibrate. More particularly, in some embodiments, the vibration generating device **302** excites vibrations at a point **304** on the crown **102** of the tire. Even more particularly, in some embodiments, the point **304** is located generally at a center **306** of the crown **102**. The center **306** of the crown **102** is defined by a line running around the circumference of the tire **100** and spaced equidistantly from the sidewalls **104**. The term "generally", when used with respect to the point **304**, indicates that the point **304** need not be disposed precisely on the halfway point of the crown **102**. Instead, the point **304** may be disposed on either side of the center **306** ±25% of the total width of the crown **102**.

In some embodiments, such as that shown in FIG. **4**, the vibration generating device **302** may be implemented with a hammer **400** that physically strikes the crown **102** of the tire **100**. One suitable hammer **400** is the model AS-1220 automated impact hammer manufactured by Alta Solutions, Inc., headquartered in San Diego, Calif. Another suitable hammer is the model 086C03 manual impact hammer sold by PCB Piezotronics, Inc., headquartered in Depew, N.Y.

In other embodiments, the vibration generating device **302** is implemented with an electrodynamic shaker (not shown) to generate vibrations through the tire **100**. One suitable electrodynamic shaker is the type 4810 device manufactured by Brüel & Kjer Sound & Vibration Measurement A/S, headquartered in Denmark. Of course, other suitable devices may be implemented as the vibration generation device **302**, as is appreciated by those skilled in the art.

Referring again to FIG. **3**, the system **300** also includes a vibration sensing arrangement **308**. The vibration sensing arrangement **308** is configured to sense vibrations at a plurality of sensing points **310**, **312** on the tire **100**. In one exemplary embodiment, the plurality of sensing points **310**, **312** include a first point **310** and a second point **312**. The first point **310** is disposed on the crown **102** of the tire **100**. More particularly, in some embodiments, the first point **310** is located generally at the center **306** of the crown **102**. The term "generally", when used with respect to the first point **310**, indicates that the first point **310** need not be disposed precisely on the halfway point of the crown **102**. Instead, the first point **310** may be disposed on either side of the center **306** ±25% of the total width of the crown **102**.

The second point **312** is disposed on one of the sidewalls **104** of the tire **100**. More particularly, in some embodiments, the second point **312** is located generally at a center **314** of the sidewall **104**. The term "generally", when used with respect to the second point **312**, indicates that the second point **312** need not be disposed precisely on the halfway point of the sidewall **104**. Instead, the second point **312** may be disposed on either side of the center **314** ±25% of the total width of the sidewall **104**.

In other exemplary embodiments, other sensing points (not shown) may be utilized to sense vibrations on the tire **100**, in addition to the first and second points **310**, **312**. Such additional sensing points may be utilized to increase the accuracy of the first frequency, as described further below.

In one exemplary embodiment, the vibration sensing arrangement **308** is implemented with a plurality of accelerometers **402**, as shown in FIG. **4**. One suitable accelerometer **402** is model A356A15 manufactured by PCB Piezotronics, Inc. In another exemplary embodiment, the vibration sensing arrangement **308** is implemented with a spindle force transducer and signal conditioner, model numbers Z16460 and 5060A12100, manufactured by Kistler Instrumente AG, headquartered in Winterthur, Switzerland. In yet another exemplary embodiment (not shown), the vibration sensing arrangement **308** may be implemented with an optical sensing device, e.g., one or more lasers. Those skilled in the art will appreciate other suitable devices for implementing the vibration sensing arrangement **308**.

The system **300** further includes a computer **315**. The computer **315** shown in the exemplary embodiment of FIG. **3** includes a central processing unit **316**, an input device **318** (e.g., a keyboard), and an output device **320** (e.g., a display). Those skilled in the art appreciate the near limitless variations for types, styles, and configurations of the computer **315**. In the exemplary embodiments, the computer **315** is capable of receiving inputs, executing instructions (e.g., a program), performing mathematical computations, and producing an output.

The computer **315** is in communication with the vibration sensing arrangement **308**. As such, signals corresponding to the vibrations of the tire **100** sensed by the vibration sensing arrangement **308** are sent from the vibration sensing arrangement **308** to the computer **315**, thus allowing the computer **315** to process the signals and the vibration data encoded therein. The computer **315** may also be in communication with the vibration generating device **302**. As such, the computer **315** may send signals to the vibration generating device **302** to control operation of the device **302**. The computer **315** may also receive signals from the vibration generating device **302** corresponding to the vibrations generated by the device **302**.

The computer **315** may include data acquisition hardware (not shown) for receiving signals from the vibration sensing arrangement **308** and/or the vibration generating device **302**. Suitable data acquisition hardware may include, but is not limited to, SCADAS Mobile equipment manufactured by LMS International, headquartered in Leuven, Belgium. The computer **315** may execute data processing software. One suitable data processing software is MATLAB, produced by The MathWorks, Inc. headquartered in Natick, Mass.

The method of determining frequencies associated with tire crown bending may be performed utilizing the above described system **300**. However, the method may be implemented with other systems, devices, and/or assemblies.

The method includes exciting vibrations through the tire **100**. For example, the impact hammer of the vibration generating device **302** may strike the tire **100** to excite vibrations therethrough. In the embodiment shown in FIG. **3**, and as described above, the tire **100** is struck at a point **304** generally at the center **304** of the crown **102**. The method also includes sensing vibrations at the plurality of points **310**, **312** on the tire **100**. In the embodiment shown in FIG. **3**, and as described above, vibrations are sensed at least at a point **310** generally at the center **304** of the crown **102** and at a point **312** generally at the center **314** of the sidewall **104**.

The method further includes determining a first frequency associated with bending of the crown **102**. This determination is based, at least partially, on phase differences between the frequency response functions of the sensed vibrations at the plurality of points **310**, **312** on the tire **100**.

In one exemplary embodiment, the determination of the first frequency associating with the bending of the crown **102** includes comparing the frequency response functions between the vibrations sensed at the plurality of sensing points **310**, **312**. More specifically, determining the first frequency associating with crown bending includes determining the frequency at which the imaginary part of the frequency response function at the first point **310** is generally out-of-phase with the frequency response function at the second point **312**. Said another way, the first frequency associating with bending occurs when the oscillation of the crown **102** of the tire **100** reverses polarity with the oscillation of the sidewall **104**. Reversal of polarity is observed by comparing the responses at relatively low frequency (e.g., 100-200 Hz) versus those at the frequency band of interest (e.g., 300-400 Hz). Additional sensing points on the tire **100** may also be utilized to ensure an even more accurate determination of the first frequency associated with bending of the crown **102**.

Testing of the tire **100** as described above may be performed under a wide variety of conditions. For instance, the tire **100** may be tested in a "free-free" environment. The free-free environment may be accomplished by suspending the tire **100** with a bungee or other flexible cord. Alternatively, the free-free environment may be achieved by supporting the tire **100** with a flexible surface, e.g., a soft foam pad. Those skilled in the art will appreciate other techniques for providing the free-free environment. The testing of the tire **100** may also be accomplished in a "fixed-free" environment. For example, the tire **100** may be mounted by fastening the wheel to a rigid inertial anchor or spindle. Notably, by testing the tire **100** as described above, a road test of the tire **100** mounted on a vehicle is not necessary. As such, the time and expense of such a road test is avoided.

The method may also include reporting the first frequency associated with bending of the crown **102** of the tire **100**. This reporting may be accomplished via the output device **320** of the computer **315** or via other techniques that are well known to those skilled in the art. By reporting the first frequency associated with bending of the crown **102**, a user may deduce whether or not the tire **100** will create undesired noise when driven on the vehicle.

One potential reporting generated by the computer **320** is shown in FIG. **5**. Specifically, FIG. **5** illustrates a graph **500** showing frequency, measured in Hertz (Hz), on the horizontal axis **502**. The vertical axis **504** of the graph **500** shows a magnitude of the imaginary part of the frequency response function. These graphs may be interpreted to indicate phase difference between the sensed vibrations at the plurality of points **310**, **312**. This interpretation is possible by viewing the polarity of the responses across the frequencies and noting the polarities of measurements in the vicinity of 100-200 Hz, peaks at **510**, **512**, **514**, **516**, and **518**, and comparing these to those measured at 300-400 Hz, namely, peaks **520**.

A first curve **508** shows vibrations at the crown **102** of the tire **100**. A second curve **506** shows vibrations corresponding at the sidewall **104** of of the tire **100**. The phase between the crown **102** and sidewall **104** motions at the local maxima transition from in-phase below approximately 200 Hz to out-of-phase above 300 Hz. In-phase is visible by identical signal polarities, while out-of-phase is visible at opposite polarities. Outward crown **102** motions are positive, while outward sidewall **104** motions are negative. As can be seen, the maximum phase shift, which illustrates the first significant, observable frequency associated with crown bending with m=5 (see FIG. **2**), occurs at about 330 Hz. When the first frequency corresponding to crown bending with m=5 occurs below a target value, for instance, 400 Hz, the tire **100** may produce an undesirable noise in the vehicle. Said simply, the tire **100** showing the characteristics shown in FIG. **5** may need to be re-designed.

While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the disclosure in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the exemplary embodiment or exemplary embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope of the disclosure as set forth in the appended claims and the legal equivalents thereof.

What is claimed is:

1. A system for determining frequencies associated with tire crown bending, comprising:

a vibration generating device configured to excite vibrations through a tire;

a vibration sensing arrangement configured to sense vibrations at a plurality of sensing points on the tire; and

a computer in communication with said vibration sensing arrangement and configured to determine a first frequency associated with bending of a crown of the tire based at least partially on phase differences between the sensed vibrations at the plurality of points on the tire.

2. The system as set forth in claim **1** wherein said vibration generating device is further defined as an impact hammer.

3. The system as set forth in claim **1** wherein said vibration sensing arrangement is further defined as a plurality of accelerometers.

4. The system as set forth in claim **1** wherein said computer is in communication with said vibration generating device and is configured to measure frequency response functions between the vibrations excited by the vibration generating device and the vibrations at the plurality of sensing points on the tire.

5. The system as set forth in claim **1** wherein the plurality of sensing points include a first point disposed on the crown of the tire.

6. The system as set forth in claim **5** wherein the first point is disposed generally at a center of the crown of the tire.

7. The system as set forth in claim **5** wherein the plurality of sensing points include a second point disposed on a sidewall of the tire.

8. The system as set forth in claim **7** wherein the second point is disposed generally on a center of the sidewall of the tire.

9. The system as set forth in claim **1** wherein said vibration generating device is further defined as a hammer disposed to strike the tire at a center of the crown.

10. The system as set forth in claim **1** wherein the computer is further configured to report the first frequency associated with bending of the crown.

11. A method of determining frequencies associated with tire crown bending, comprising:

exciting vibrations through a tire;

sensing vibrations at a plurality of points on the tire; and

determining a first frequency associated with bending of a crown of the tire based at least partially on phase differences between the sensed vibrations at the plurality of points on the tire.

12. The method as set forth in claim **11** wherein sensing vibrations at a plurality of points on the tire includes sensing vibrations at a first point disposed on the crown of the tire.

13. The method as set forth in claim **12** wherein the first point is disposed generally at a center of the crown of the tire.

14. The method as set forth in claim **12** wherein sensing vibrations at a plurality of points on the tire includes sensing vibrations at a second point disposed on a sidewall of the tire.

15. The method as set forth in claim **14** wherein the second point is disposed generally on a center of the sidewall of the tire.

16. The method as set forth in claim **14** wherein determining the first frequency associated with bending of the crown comprises measuring frequency response functions between the vibrations excited by the vibration generating device and the vibrations at the plurality of sensing points on the tire.

17. The method as set forth in claim **16** wherein determining a first frequency associated with bending of the crown comprises determining the frequency at which the frequency response function at the first point is generally out-of-phase with the frequency response function at the second point.

18. The method as set forth in claim **11** further comprising reporting the first frequency associated with bending of the crown of the tire.

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